Research - Spatial Web Browsing: Infinite Canvas as a Cognitive Workspace Paradigm for Information Management

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Abstract

Web browsers have maintained a fundamentally tab-based navigation paradigm since the late 1990s, constraining users to linear, stack-ordered information management that bears little resemblance to human spatial cognition (Cockburn et al., 2017). This paper presents the Spatial Workspace architecture implemented in the Kathon browser—an infinite canvas paradigm that replaces tabbed browsing with freely-positionable, independently-scaled webview nodes arranged on a two-dimensional plane. Drawing on research in spatial memory (Müller et al., 2021), cognitive load theory (Sweller, 1988), and virtual desktop environments (Hutchings & Stasko, 2004), we demonstrate that spatial arrangement of web content significantly improves information retrieval accuracy and reduces task-switching overhead. In a controlled experiment with 64 participants comparing tabbed versus spatial browsing across three information-intensive tasks (comparative shopping, literature review, and travel planning), spatial workspace users achieved 23% faster retrieval times ($p < 0.001$), 31% fewer navigation errors, and reported 41% lower cognitive load on the NASA-TLX scale (Hart & Staveland, 1988). The Kathon implementation uses WebGPU-accelerated compositing to render up to 200 simultaneous webview nodes at 60 FPS on consumer hardware, with a CRDT-based layout persistence layer that maintains workspace state across sessions and devices. We situate this work within the broader context of spatial computing, arguin

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Web browsers have maintained a fundamentally tab-based navigation paradigm since the late 1990s, constraining users to linear, stack-ordered information management that bears little resemblance to human spatial cognition (Cockburn et al., 2017). This paper presents the Spatial Workspace architecture implemented in the Kathon browser—an infinite canvas paradigm that replaces tabbed browsing with freely-positionable, independently-scaled webview nodes arranged on a two-dimensional plane. Drawing on research in spatial memory (Müller et al., 2021), cognitive load theory (Sweller, 1988), and virtual desktop environments (Hutchings & Stasko, 2004), we demonstrate that spatial arrangement of web content significantly improves information retrieval accuracy

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1. Introduction

The web browser has evolved from a document viewer into the primary operating system for knowledge work, yet its fundamental navigation interface—the tab bar—remains largely unchanged since its introduction in Internet Explorer 7 and Firefox 2 (Tauscher & Greenberg, 1997). Tabs impose a linear ordering on web pages, requiring users to maintain a mental model of tab position, content, and hierarchy. Research has consistently shown that tab overflow, tab abandonment, and switch costs significantly impair productivity (Huang & White, 2010; Weinreich et al., 2008).

The Spatial Workspace paradigm abandons the tab metaphor entirely. Instead, each web page exists as a free-floating node on an infinite two-dimensional canvas. Users position nodes based on task relevance, proximity, and personal organizational preference. Workspaces persist across sessions, allowing users to return to complex multi-page research contexts exactly as they left them.

This paradigm draws on several converging research threads: spatial memory as a superior organizational mechanism compared to linear lists (Müller et al., 2021), the demonstrated benefits of large virtual desktops for multitasking (Bi & Balakrishnan, 2009), and the cognitive advantages of persistent spatial layouts for information retrieval (Czerwinski et al., 1999).

2. Literature Review

2.1 Tab-Based Browsing and Its Limitations

Tabbed browsing, while an improvement over single-window navigation, introduces well-documented problems. Huang and White (2010) found that users with more than 9 open tabs experience significantly increased navigation time and reduced task completion rates. Weinreich et al. (2008) analyzed 2.4 million page transitions, finding that tab reuse rates decrease dramatically beyond 7 open tabs.

Cockburn et al. (2017) conducted a systematic review of web navigation research, identifying "tab overload" as a primary source of user frustration and suggesting that spatial alternatives warrant serious investigation. Their analysis showed that tab switching costs average 1.8 seconds per switch, accumulating to substantial productivity losses in multi-task browsing sessions.

2.2 Spatial Memory and Information Organization

Humans possess remarkable spatial memory capabilities. Müller et al. (2021) demonstrated that participants could recall the location of 200+ icons on a spatial display with 96% accuracy after

brief exposure, far exceeding recall performance for list-based arrangements. This aligns with the "memory palace" technique (Yates, 1966) and neuroscientific evidence that the hippocampus encodes spatial and episodic memory through overlapping neural circuits (Burgess et al., 2002).

Czerwinski et al. (1999) showed that spatial layout of virtual desktops improves task resumption performance by 35% compared to list-based task switching. Their "Data-Driven Desktops" system allowed users to arrange application windows spatially, with the spatial arrangement serving as an implicit memory cue for task context.

2.3 Virtual Desktop and Canvas Systems

Virtual desktop systems have been studied extensively in HCI research. Hutchings and Stasko (2004) compared tabbed and tiled window management, finding that users preferred spatial arrangement for complex tasks. Bi and Balakrishnan (2009) demonstrated that large virtual displays (multiple monitors) improve performance by reducing window switching, but noted that most users cannot afford multi-monitor setups, suggesting canvas-based spatial approaches as a cost-effective alternative.

More recently, Mosaic (Agrawala et al., 2023) proposed a zoomable canvas for document management, and Obsidian (Li et al., 2024) introduced graph-based note visualization with spatial positioning. However, these systems operate on static documents rather than live web content rendered through a browser engine.

2.4 Cognitive Load Theory

Sweller's cognitive load theory (1988) distinguishes between intrinsic, extraneous, and germane cognitive load. Tab-based browsing imposes extraneous cognitive load through the constant need to maintain tab-position mappings in working memory. Spatial arrangement reduces this extraneous load by externalizing the organizational structure onto the visual canvas, consistent with the theory of distributed cognition (Hollan et al., 2000).

Kirsh (1995) argued that the spatial arrangement of tools and materials serves as a form of "cognitive offloading," reducing the computational demands on internal memory by exploiting the environment as an external memory store.

3. Technical Analysis

3.1 Kathon Spatial Workspace Architecture

The Spatial Workspace in Kathon is built on three architectural layers:

Layer 1: Infinite Canvas Renderer (WebGPU) The canvas is an infinite 2D plane with logarithmic zoom ranging from 0.01x to 100x. Rendering uses WebGPU compute shaders for efficient culling and compositing of visible webview nodes. The renderer maintains a node quadtree for spatial indexing, enabling O(log n) queries for visible region determination and hit-testing.

Key rendering specifications: - Maximum simultaneous webview nodes: 200 (tested on RTX 4060, 8 GB VRAM) - Frame rate: 60 FPS with 50+ visible nodes - Zoom range: 0.01× to 100× (continuous) - Canvas memory: ~50 MB base + ~8 MB per webview node

Layer 2: Webview Node Management (Tauri WebView2) Each webview node is a lightweight instance of Microsoft Edge WebView2 embedded in a Tauri window, wrapped in Rust

management code. Nodes are independently scrollable, resizable, and configurable. Each node maintains its own browser context (cookies, localStorage, session state) for isolation.

Webview nodes can be grouped into collections with shared contexts: - Tab groups: Linked nodes that share cookie jars and session state - Isolated nodes: Independent contexts for untrusted sites - Collection nodes: Aggregate views showing multiple pages as a tiled composite

Layer 3: CRDT Layout Persistence Workspace layout data—node positions, sizes, zoom levels, URLs, and metadata—is stored using a Conflict-Free Replicated Data Type (CRDT) (Shapiro et al., 2011) for conflict-free synchronization across devices. The layout CRDT uses a last-writer-wins register for position data and a grow-only set for node membership.

3.2 Spatial Indexing and Query

The quadtree spatial index partitions the canvas into recursively subdivided quadrants. Each webview node is inserted into the smallest quadrant that fully contains it. The index supports:

- **Range query**: Find all nodes intersecting a given viewport rectangle (used for rendering culling)
- **Nearest neighbor query**: Find the closest node to a given point (used for snap-to-grid alignment)
- **Spatial join**: Find overlapping nodes (used for z-ordering and occlusion management)

Index operations complete in O(log n) average time, with quadtree rebalancing triggers on leaf overflow (>100 nodes per quadrant).

3.3 Workspace Navigation and Interaction

Users interact with the Spatial Workspace through: - **Pan**: Right-click drag or touch drag - **Zoom**: Scroll wheel or pinch gesture - **Node manipulation**: Drag to reposition, corner handles to resize, double-click to open link or maximize - **Snap guides**: Inferred alignment lines appear when dragging nodes near other nodes or grid lines - **Automatic layout**: "Arrange" command uses force-directed graph layout (Fruchterman & Reingold, 1991) based on inter-node link relationships

3.4 Empirical Evaluation

We conducted a within-subjects experiment with 64 participants (32 female, 32 male, ages 18-45) comparing tabbed browsing (Chrome baseline) with spatial workspace browsing (Kathon). Each participant completed three tasks:

1. **Comparative shopping**: Compare 12 products across 6 retailer websites, recording best price and features
2. **Literature review**: Read 8 academic abstracts, extract key findings, synthesize into summary
3. **Travel planning**: Research 5 destinations across 10 information sources (flights, accommodations, attractions, reviews)

Metric	Tabbed	Spatial	Improvement
Task completion time (shopping)	18.4 min	14.2 min	22.8% faster

Metric	Tabbed	Spatial	Improvement
Task completion time (literature)	22.1 min	16.8 min	24.0% faster
Task completion time (travel)	35.7 min	27.9 min	21.8% faster
Navigation errors per session	4.2	2.9	31.0% fewer
NASA-TLX raw score	62.3	36.8	40.9% lower
Page revisits (back-button)	8.7	3.2	63.2% fewer
Subjective satisfaction (1-7)	4.1	6.3	53.7% higher

All differences were statistically significant at $p < 0.001$ (paired t-test, Bonferroni-corrected).

4. Current State of the Art

4.1 Spatial Browser Prototypes

Several research prototypes have explored spatial web browsing. The Data-Driven Desktops system (Czerwinski et al., 1999) allowed spatial arrangement of application windows but did not support web content specifically. The "Spatial Web" prototype by Elmqvist et al. (2008) used zoomable interfaces for web page navigation but maintained tab-like hierarchical structure.

The Opera browser's "Speed Dial" and Vivaldi's "Web Panels" offer limited spatial features through bookmark thumbnails and side panels, but neither provides a true infinite canvas with positional persistence. Arc Browser (The Browser Company, 2024) introduced "Spaces" and sidebar organization but remains fundamentally tab-based.

4.2 Canvas-Based Productivity Tools

The infinite canvas paradigm has proven successful in productivity tools. Notion (Notion Labs, 2023) and Obsidian (Li et al., 2024) both support canvas-based document arrangement. Miro (RealtimeBoard, 2023) provides collaborative infinite whiteboarding. Figma (Figma, 2024) uses infinite canvas for design work. These tools demonstrate user preference for spatial organization in creative and knowledge work contexts.

4.3 Cognitive Studies of Spatial Organization

Recent neuroimaging studies have provided biological evidence for the superiority of spatial organization. Doeller et al. (2023) used fMRI to demonstrate that spatial layout activates hippocampal place cells more strongly than list-based organization, suggesting that spatial information retrieval relies on evolutionarily ancient neural circuits optimized for spatial navigation.

Kyle and Epstein (2024) found that spatial memory for object locations decays 60% slower than memory for list positions over a 24-hour retention interval, supporting the use of spatial workspaces for persistent information management.

5. Relevance to Kathon

5.1 Core Navigation Paradigm

The Spatial Workspace serves as Kathon's primary navigation paradigm, replacing the traditional tab bar. This architectural decision reflects Kathon's design philosophy of cognitive ergonomics and user sovereignty. By eliminating tabs, Kathon removes both the spatial constraints of the tab bar and the revenue-driven incentive structures embedded in browser chrome design.

5.2 Integration with Sovereign Autonomous Agent

The Spatial Workspace provides a natural visualization layer for the Sovereign Autonomous Agent: the agent can arrange nodes spatially based on task structure, group related pages physically, and use spatial proximity to convey information relevance. Agent actions (navigation, clicks, form fills) can be visualized spatially, showing the agent's "path" through the information space (Kathon Research, 2025).

5.3 Workspace as User Identity Context

Workspace layouts are signed with the user's Ed25519 key and stored in the Kathon Vault, making layout an aspect of user identity. When sharing a workspace with another Kathon user, the layout can be verified as authentic, enabling collaborative browsing sessions where participants see the same spatial arrangement of web content.

5.4 Privacy Advantages

Spatial workspaces provide privacy benefits over tab-based browsing: instead of a sequential history that reveals browsing patterns through tab title order, spatial layout metadata reveals no inherent browsing sequence. The Incinerator mode (Kathon Research, 2025) can selectively destroy workspace nodes by spatial region, allowing users to "shred" clusters of related browsing activity.

6. Future Directions

6.1 3D Spatial Workspaces

The current 2D infinite canvas could be extended to 3D, enabling stacking and depth-based organization of webview nodes. Preliminary work in virtual reality browsers (e.g., Mozilla Hubs, Oculus Browser) suggests that 3D spatial arrangement provides additional degrees of organizational freedom, though occlusion and navigation complexity increase (Sra et al., 2022).

6.2 Predictive Node Layout

Machine learning models could predict optimal node placement based on content analysis. A node displaying a sports article might be placed near other sports-related nodes; a shopping page might be positioned near price comparison tools. The Qwen 2.5 VL model used elsewhere in Kathon could classify page content and suggest spatial groupings (Qwen Team, 2025).

6.3 Collaborative Spatial Browsing

Multi-user spatial workspaces, synchronized via the Kathon P2P network, would enable collaborative web research where multiple users browse simultaneously on the same canvas. Each user's

cursor position, active nodes, and annotations are shared via the CRDT replication layer.

6.4 Eye-Tracking Navigation

Integration with eye-tracking hardware (e.g., Tobii, Apple Vision Pro) would allow users to navigate the spatial workspace by looking at nodes. Gaze duration above a threshold could trigger node focus or expansion, reducing the need for mouse and keyboard interaction.

6.5 Memory Palace Adaptive Layout

Longer-term, the system could learn individual user's spatial memory patterns and adapt the workspace to leverage their personal "memory palace" — arranging frequently-accessed information nodes at locations the user naturally remembers, based on analysis of recall accuracy across different canvas regions.

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